10/522908
DT12 Rec'd PCT/PTO 31 JAN 2005

GENERATOR/MOTOR SYSTEM AND METHOD FOR OPERATING THIS GENERATOR/MOTOR SYSTEM

[0001] The invention relates to a generator/motor system as claimed in the preamble of claim 1, and to a method for operating this generator/motor system.

[0002] At present, efforts are being made in motor vehicles with an internal combustion engine to combine the starter and generator to form a single electric machine.

[0003] However, during these efforts there is a problem, even at the general design stage, that two completely contradictory requirements have to be met.

[0004] On the one hand, in order to start and speed up an internal combustion engine it is necessary to apply an extremely high turning torque. This torque may be, depending on the engine capacity or cylinder number of the internal combustion engine, greater than 240 Nm. Furthermore, the electric machine must also be able to provide torque reserves for speeding up the internal combustion engine to the starting speed.

[0005] On the other hand, after the internal combustion engine has been successfully started, the electric machine which is designed as a starter/generator should operate predominantly as a generator in order to feed into the on-board power system of the motor vehicle. In this context, there is a need for a constant output of power over the extremely spread out rotational speed range, predefined by the internal combustion engine, from 600 to 6000 1/min (motor) with the highest possible efficiency.

[0006] It is virtually impossible to meet both requirements economically with a standard drive composed of a three-phase rotational field machine 30 and voltage-impressing pulse-controlled inverter (PRW) 31 in a rotational field bridge circuit with filter capacitor C, as shown in Fig. 3A.

[0007] A problem which it is necessary to overcome in this context is the necessary miniaturization and complete integration of the power electronics. The necessary filter capacitors are an impediment to integration. In particular, given the relatively low on-board power system voltage of 42 V, phase currents of

approximately 1200 A in asynchronous machines are currently under discussion in order to generate the starting torques which are required. The intermediate circuit capacitors C, such as are shown, for example, in Fig. 3A which shows the design of a conventional drive system with rotational field machine 30, pulse-controlled inverter 31 and intermediate circuit capacitor C, assume considerable dimensions in this context, and these dimensions are an impediment to integration.

[0008] Furthermore, first measurements in the absorber space have shown that it is not possible to make any compromises here. The filtering is necessary in order to fulfill the stringent EMC requirements in motor vehicles. It is imperative to reduce the currents of the machine and thus the filter currents while keeping the other properties of the drive the same.

[0009] The configuration of the drive system with a rotational field machine and pulse-controlled inverter is conventionally as follows, described with reference to Fig. 3B.

[0010] Fig. 3B shows a conventional rotational speed/torque characteristic. The continuous line in Fig. 3B shows what can be achieved with a specific configuration of the rotational field machine and an associated pulse-controlled inverter power.

[0011] If, for example, the starting torque is to be increased while retaining the standard pulse-controlled inverter topology, i.e. one pulse-controlled inverter in a six pulse bridge circuit, and retaining the pulse-controlled inverter (apparent) power, the winding of the rotational field machine must be correspondingly changed. In the simplest case, more turns with thinner wires are formed. This leads to the characteristic curve shown by dashed lines in Fig. 3B. It is apparent that although this measure can increase the starting torque with an unchanged pulse-controlled inverter power, this can only be achieved at the cost of the generator power at relatively high rotational speeds. The configuration point drops correspondingly. Owing to the relatively high number of turns, the rotational field machine reaches its field weakening mode, i.e. the modulation limit of the pulse-controlled inverter, earlier and is able to output less power later during the generator mode.

[0012] In particular in motor vehicle applications, and specifically starter/generator arrangements, the costs for the pulse-controlled inverter also play a decisive role. The costs of a pulse-controlled inverter are nowadays no longer assessed very much

according to the current strength which the pulse-controlled inverter has to bear but rather according to the current strength which has to be commutated in the topology. This characteristic variable determines the filter expenditure which has to be made particularly in the especially EMC-sensitive field of the car industry. In addition, the filters are an impediment to miniaturization, as are in particular also the reliability problems at high temperatures. For this reason it is necessary to attempt to configure the power electronics in the drive circuit as efficiently as possible, in particular to reduce the currents to be commutated.

[0013] M. Osama, T.A. Lipo "Modeling and analysis of a wide-speed-range induction motor drive based on electronic pole changing", IEEE Transactions on Industry Application, Vol. 33, No. 5, September/October 1997 describes a rotational field machine with poles which can be switched over, two winding systems and two separate pulse-controlled inverters. However, less than optimum winding factors are obtained with the specific combination of the winding systems so that the rotational field machine cannot convert the maximum possible pulse-controlled inverter current for a given overall size of the pulse-controlled inverter into the torque in an optimum way. The dynamic behavior when the rotational field machine is switched over is not possible without corresponding torque transient effects, which can throw up particular problems in the drive phase, which can adversely affect the user's comfort. The Dahlander circuit which has also been known for a long time has a similar problem.

[0014] In DE 199 31 010 A1, a so-called diode-clamp double-three-level converter, which is known per se, is actuated by a novel pulse method in such a way that a parallel/serial switchover of the two winding systems can be brought about. At the same time, the number of poles of the rotational field machine can be retained during switching over. Since the switching over is brought about by a different predefinition of the voltage vectors, the switching over also takes place with little noise and without torque transient effects. In addition, the winding systems can also be "pivoted" in their phase so that a further significant reduction in the intermediate circuit current to be filtered can be brought about. Although this system is most developed technically, it is very complicated and costly.

[0015] For this reason, a system with a feed power converter and a machine power converter, that is to say a genuine converter, would be more suitable since then a higher degree of flexibility can be achieved. Such a genuine converter is

described, for example, in L. Sack, "Reduction of losses in the DC-link capacitor of two-stage self-commutated converters", Proceedings of the EPE '99, Lausanne, Switzerland. In said document it is also possible to achieve a significant reduction in the ripple current to be filtered by synchronizing the pulse patterns. If it is possible to reduce the ripple currents, the efficiency of the system can also be increased simultaneously since a relatively large amount of energy at the feed power inverter of the capacitor is conventionally also converted into dissipated energy.

[0016] For this reason, the object of the present invention is to construct a generator/motor system and a method for operating this motor/generator system in which and with which the currents which are to be commutated in the pulse-controlled inverter can be significantly reduced in a simple and cost-effective way.

[0017] This object is achieved according to the invention by means of a generator/motor system having the features of patent claim 1 as well as a method for operating this generator/motor system having the features of claim 8.

[0018] It is advantageous in particular that by dividing the pulse-controlled inverter into two identical pulse-controlled inverters with half the rated power each it becomes possible to operate the generator/motor system both in a star circuit and in a single phase circuit and as a result to obtain uniform current loading of the filter over a wide range. As a result, both a peak current during starting and a configuration of the filter to this peak load are avoided since in the star circuit only approximately half the conventional phase currents have to be commutated.

[0019] This, and further objects, advantages and features of the invention, become apparent from the following description of a preferred exemplary embodiment in conjunction with the drawing, in which:

[0020] Fig. 1 is a circuit diagram of a generator/motor system according to the invention,

[0021] Fig. 2 is a torque/rotational speed characteristic of a conventional generator/motor system and an equivalent torque/rotational speed characteristic of the generator/motor system according to the invention, and

[0022] Fig. 3, with figs 3A and 3B, shows a conventional drive system and an associated rotational speed/torque characteristic.

[0023] Fig. 1 shows a circuit diagram of a generator/motor system according to the invention. The generator/motor system according to the invention has a three phase rotational field machine DM whose individual generator phase windings or machine phases a, b and c are connected to a first and second pulse-controlled inverter PWR1 and PWR2. The first and second pulse-controlled inverters PWR1 and PWR2 are of identical design and have the same rated power. Each pulse-controlled inverter PWR1 and PWR2 is composed of six electronic branch switches S1 to S6 which are formed, for example, by MOS transistors or IGBT (Integrated Gate Bipolar Transistors) and are arranged symmetrically in series in three branch pairs, and of a filter capacitor C1 and C2 which are connected in parallel with the pulse-controlled inverter. As a result of the division into the first and second pulse-controlled inverters PWR1 and PWR2 it is possible to select significantly smaller capacitors for these filter capacitors C1 and C2, which have an advantageous effect on overall size and power loss.

[0024] Between the two pulse-controlled inverters PWR1 and PWR2, an electronic switch S7, via which a positive busbar of the first pulse-controlled inverter PWR1 can be connected to the positive busbar of the second pulse-controlled inverter PWR2, and disconnected from it, is formed in parallel with the machine phases a, b, c. This electronic switch S7 can, but does not need to, be bidirectional. A power MOS transistor with a parasitic reverse-biased diode can be used as a nonbidirectional switch for the switch S7.

[0025] The method of operation of the generator/motor system according to the invention will now be explained below with reference to Fig. 1.

[0026] The generator/motor system according to the invention permits two different operating modes.

1. Operation with a star circuit

[0027] In a star circuit the branch switches S1, S2 and S3 are closed and the branch switches S4, S5 and S6 as well as the electronic switch S7 are open. The pulse-controlled inverter PWR1 thus forms a star point for the three machine phases

a, b and c which are represented. In voltage-impressing pulse-controlled inverters PWR1 and PWR2 in a six pulse bridge circuit, the potential of the star point jumps between 1/3 and 2/3 of the voltage of the intermediate circuit as a function of the switched-on voltage vectors. If the switches are composed of MOSs the reverse-biased diode does not need to be activated.

[0028] Since, compared with the prior art, only half the pulse-controlled inverter, specifically the pulse-controlled inverter PWR1 is now available for conducting current, the rotational field machine DM acquires more stator turns as compensation for this. The flux linkage, which determines the torque, is thus retained. As a result, the characteristic curve branch 1 in Fig. 2 is obtained. An equally large torque is implemented but since only half the circuit participates in the conversion of energy, specifically the pulse-controlled inverter PWR1, it is also the case that only approximately half the original phase currents have to be commutated. If the same ripple of the intermediate circuit voltage is permitted, the filter expenditure is also approximately halved.

2. Operation with a single phase circuit ("open delta")

[0029] Of course, owing to the approximately double number of stator turns of the rotational field machine DM, the modulation limit of the pulse-controlled inverter PWR1 is already reached at half the rotational speed in comparison with the standard solution. The star point which is formed by the pulse-controlled inverter PWR1 is then eliminated and the generator/motor system is operated with a single phase circuit. For this purpose, the electronic switch 7 is closed and the pulse-controlled inverter PWR1 is actuated in such a way that each phase receives its own half bridge, i.e. all the branch switches of the first and second pulse-controlled inverter PWR1 and PWR2 are closed. By reducing the terminal voltage to approximately half, the modulation limit of the generator/motor system according to the invention is moved further toward higher rotational speeds. The same dimensioning point is implemented. A characteristic curve branch 2 of the characteristic curve of the generator/motor system according to the invention is then approximately covered with that of one standard circuit.

[0030] As a result, the objective is achieved using the switchable generator/motor system according to the invention. By switching over the motor/generator system the

current loading of the filter is homogenized over a wide range. The peak current during starting and the configuration of the filter to this peak loading is thus avoided.

[0031] Switching over from one operating mode to the other is carried out according to the invention in a way which is optimized in terms of efficiency. Only the maximum characteristics are shown in Fig. 2. With a partial load, a control unit which can be implemented as software module assumes the precise characteristic-diagram-dependent switchover point in a way which is optimized in terms of efficiency. Since the switching over takes place without an impact, it is in theory possible to switch over as often as possible.

[0032] Furthermore, an advantage with the circuit according to the invention is that some of the capacitor quiescent currents can be switched off using the switch S7.

[0033] In addition the reliability is increased since the single phase circuit permits operation, however somewhat restricted operation, with asynchronous machines even if an electronic switch in the generator/motor system has a fault, for example short circuit or disconnection). It is then always also possible to build up a rotational field, which is not possible with a standard bridge circuit with three phases.

[0034] In addition, the efficiency is increased since the reduction in the ripple currents not only leads to a reduction in the filters overall but also to a reduction in the filter losses.